Ultra-Large Scale Cosmology

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Outline

1. Potentiality of Cosmology on the Largest Scales

   - Gravity *(search for modified gravity, tests of general relativity)*

   - Primordial Universe *(inflation, e.g. via primordial non-Gaussianity)*

2. Novel Ways to Access the Ultra-Large Scale Information

   - Intensity mapping

   - Multi-tracer technique

3. Importance of Ultra-Large Scales for Future Surveys

Primordial Non-Gaussianity

$$\Phi = \phi + f_{\mathrm{NL}} * \left(\phi^2 + \langle\phi^2\rangle\right)$$

- Predicted in many scenarios of inflation

- 2nd-order density perturbations induce a relativistic $f_{\mathrm{NL}} = -5/3$

[Bartolo, Matarrese & Riotto, 2004;
Bruni, Hidalgo & Wands, 2014]
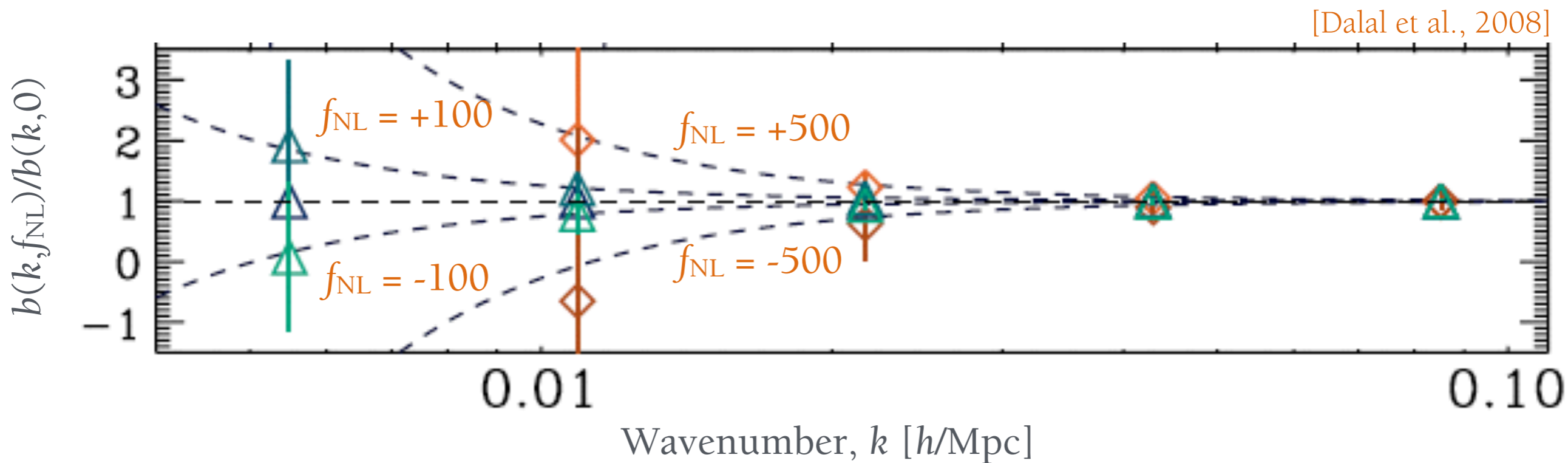
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- Tightest available constraints from CMB: $|f_{\mathrm{NL}}| < 10$
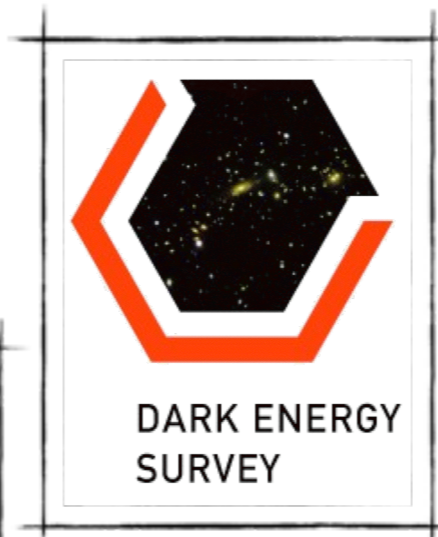
  [Planck Collaboration, 2015]

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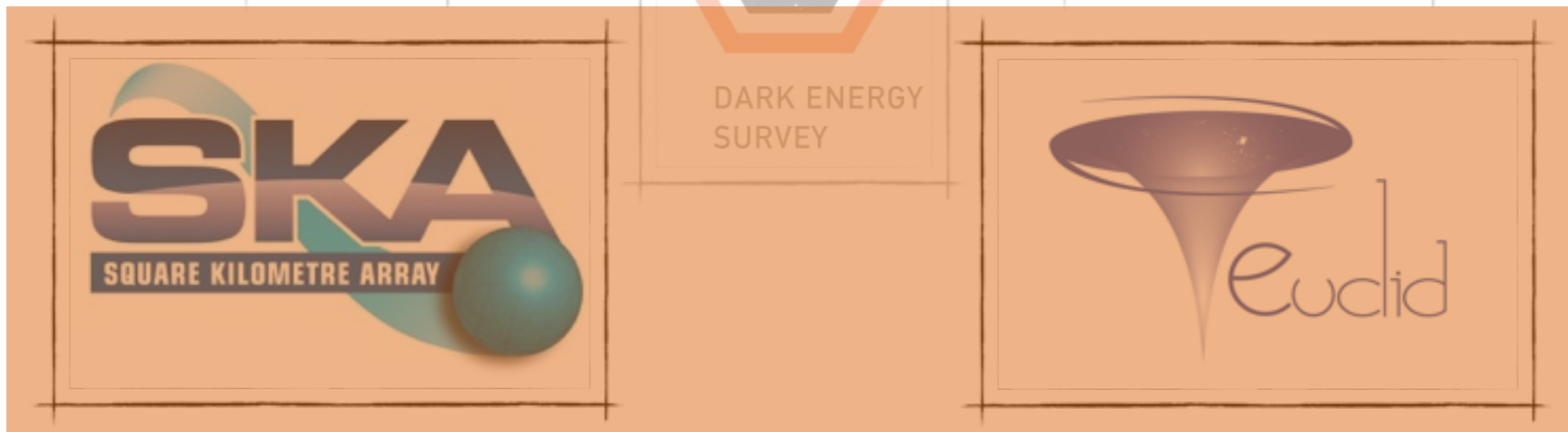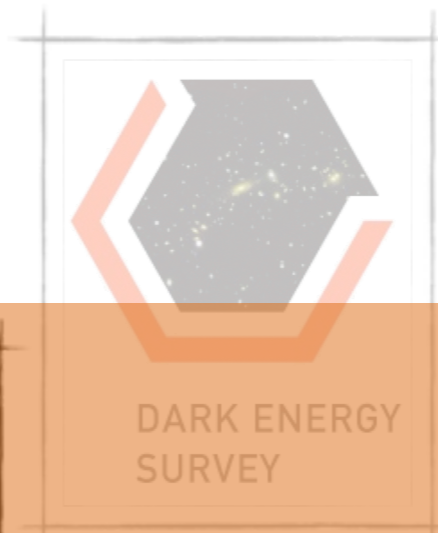
- Accuracy of $O(1)$ possible w/ future large-scale galaxy surveys

[Dalal et al., 2008]

Accessing the Largest Scales

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- Forecasts on primordial non-Gaussianity for galaxy surveys

- $\sigma(f_{NL}) \sim 1.5$
  [SC, Santos & Maartens, 2015]

- $\sigma(f_{NL}) \sim 2-4$
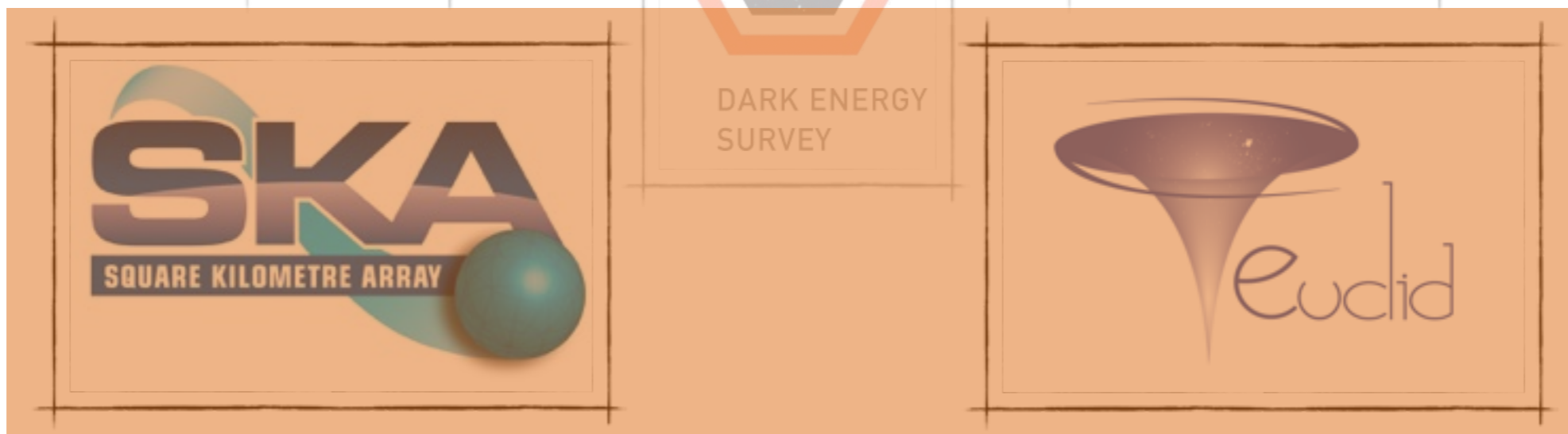 [Carbone, Matarrese & Verde, 2008; Giannantonio *et al.*, 2012]

Accessing the Largest Scales

- How to go below the $f_{NL} = 1$ divide?

 1. Probe huge volumes

  2. Beat cosmic variance

Accessing the Largest Scales

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    1. Probe huge volumes *(high sensitivity at high-z over large sky areas)*

    2. Beat cosmic variance *(we've got only one Universe to observe!)*

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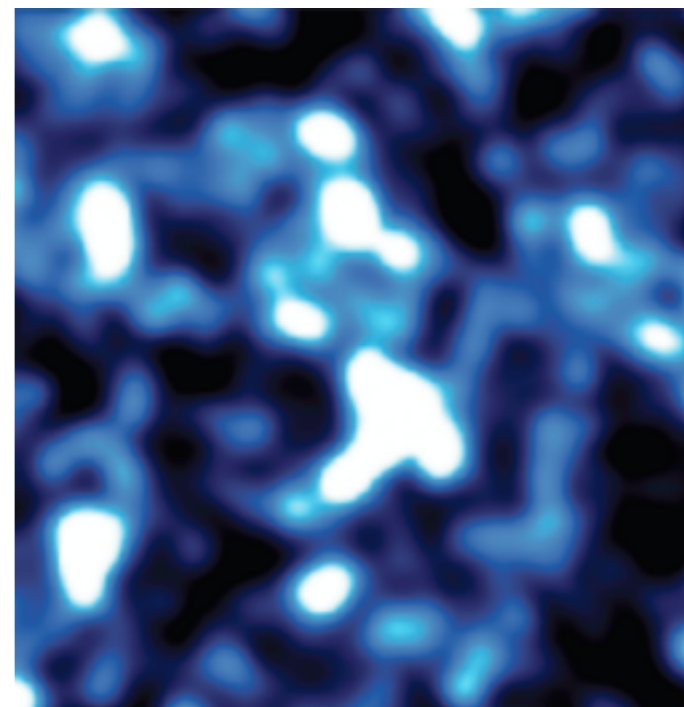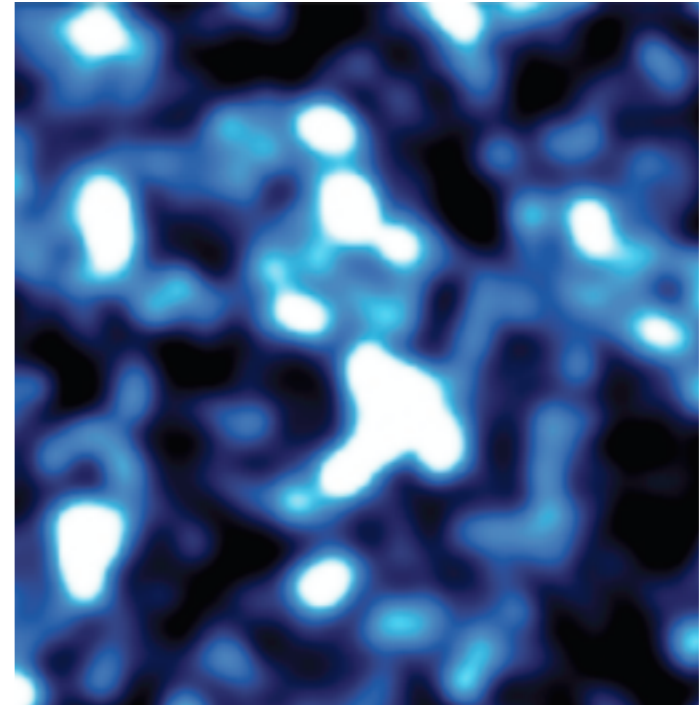 2. Beat cosmic variance *(we've got only one Universe to observe!)*

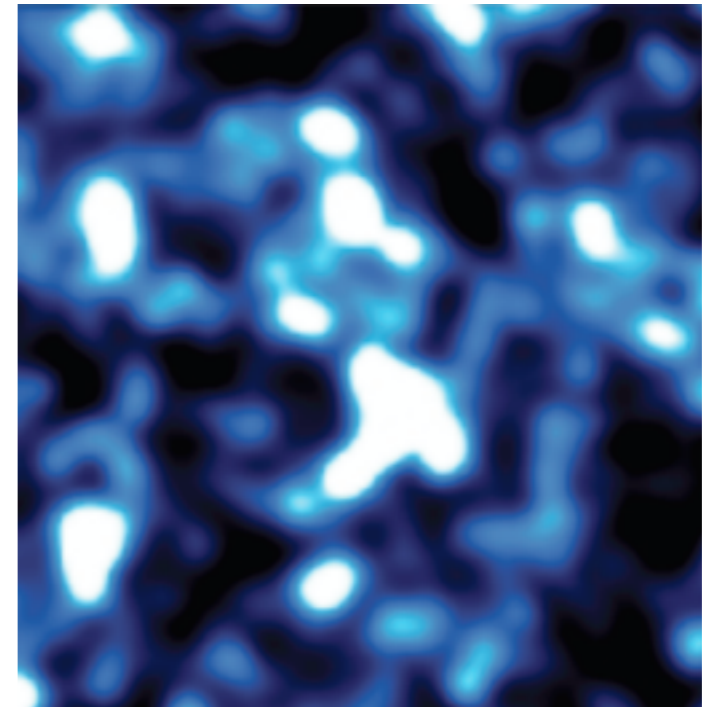[SDSS-III BOSS, 2012]
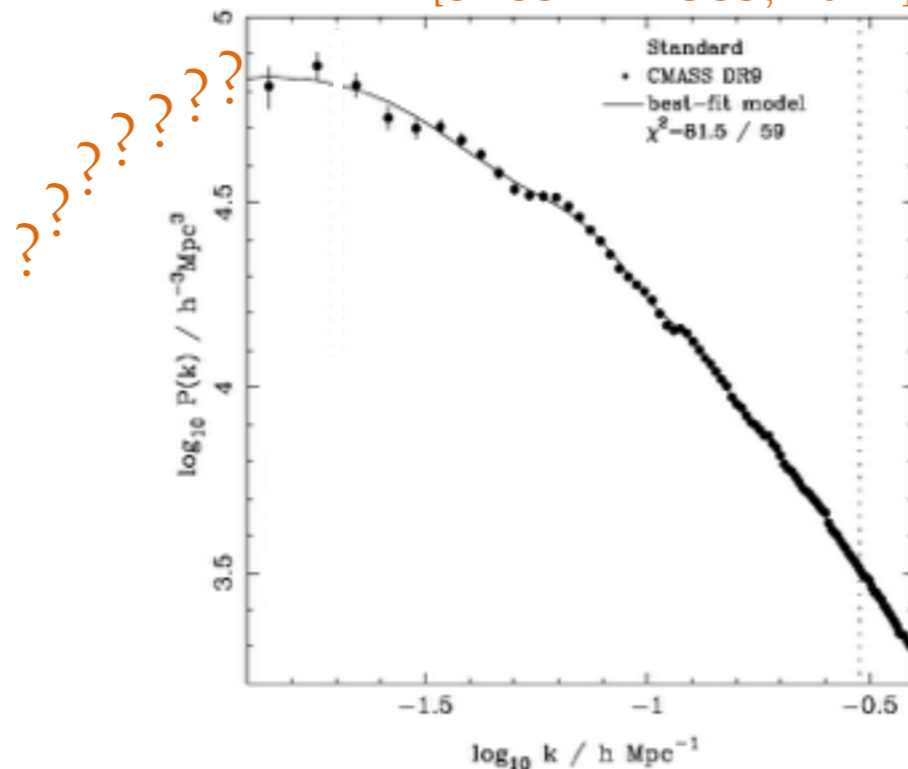
Intensity Mapping

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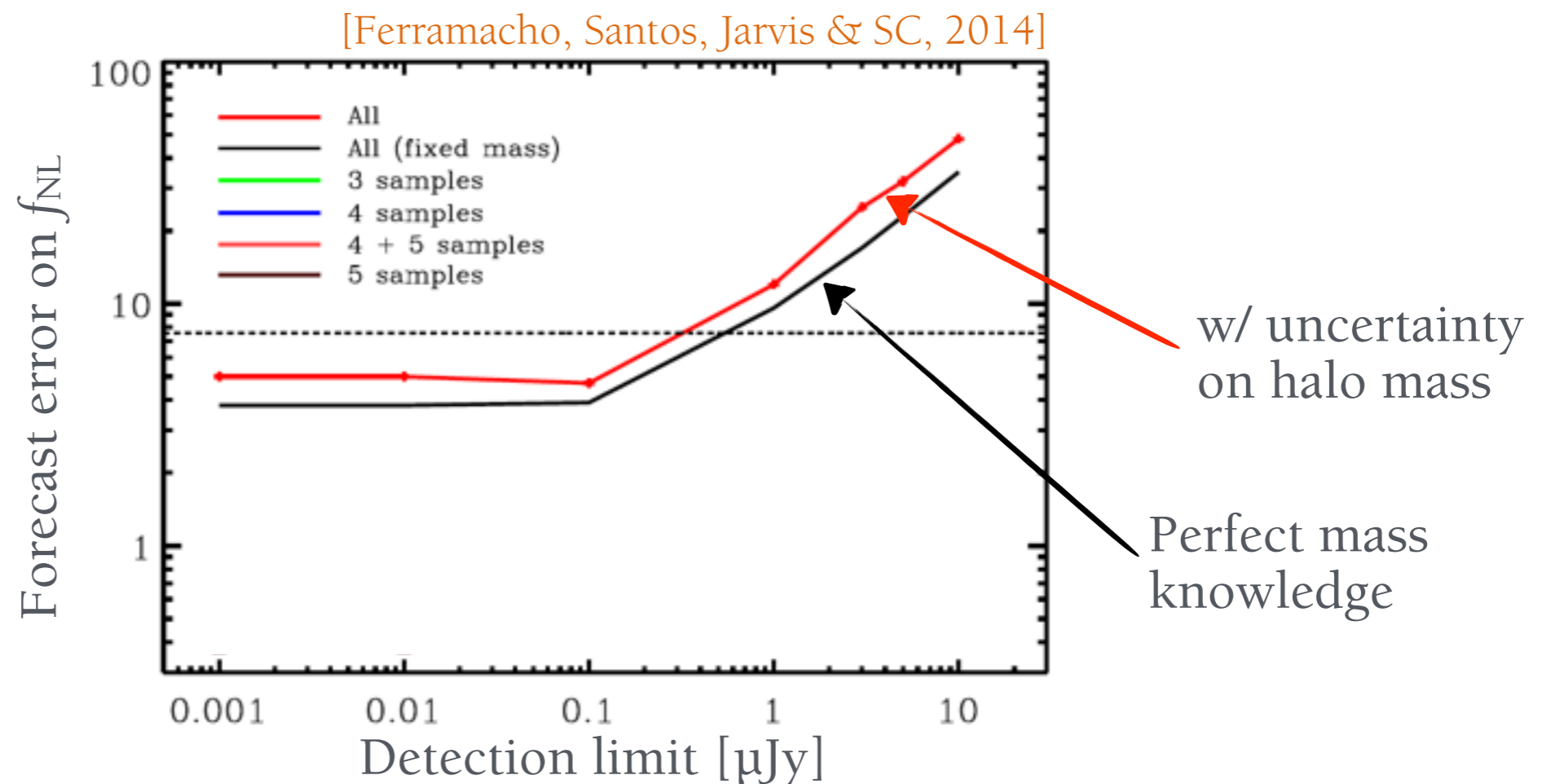
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- Developed for radio dish surveys / interferometers: SKA $\sigma(f_{NL}) \sim 1$

  [SC, Santos, Ferreira & Ferramacho, 2013]

Multi-Tracer Technique

- Comparing the relative clustering of different populations of tracers

  [Seljak, 2009]

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[Ferramacho, Santos, Jarvis & SC, 2014]

w/ uncertainty on halo mass

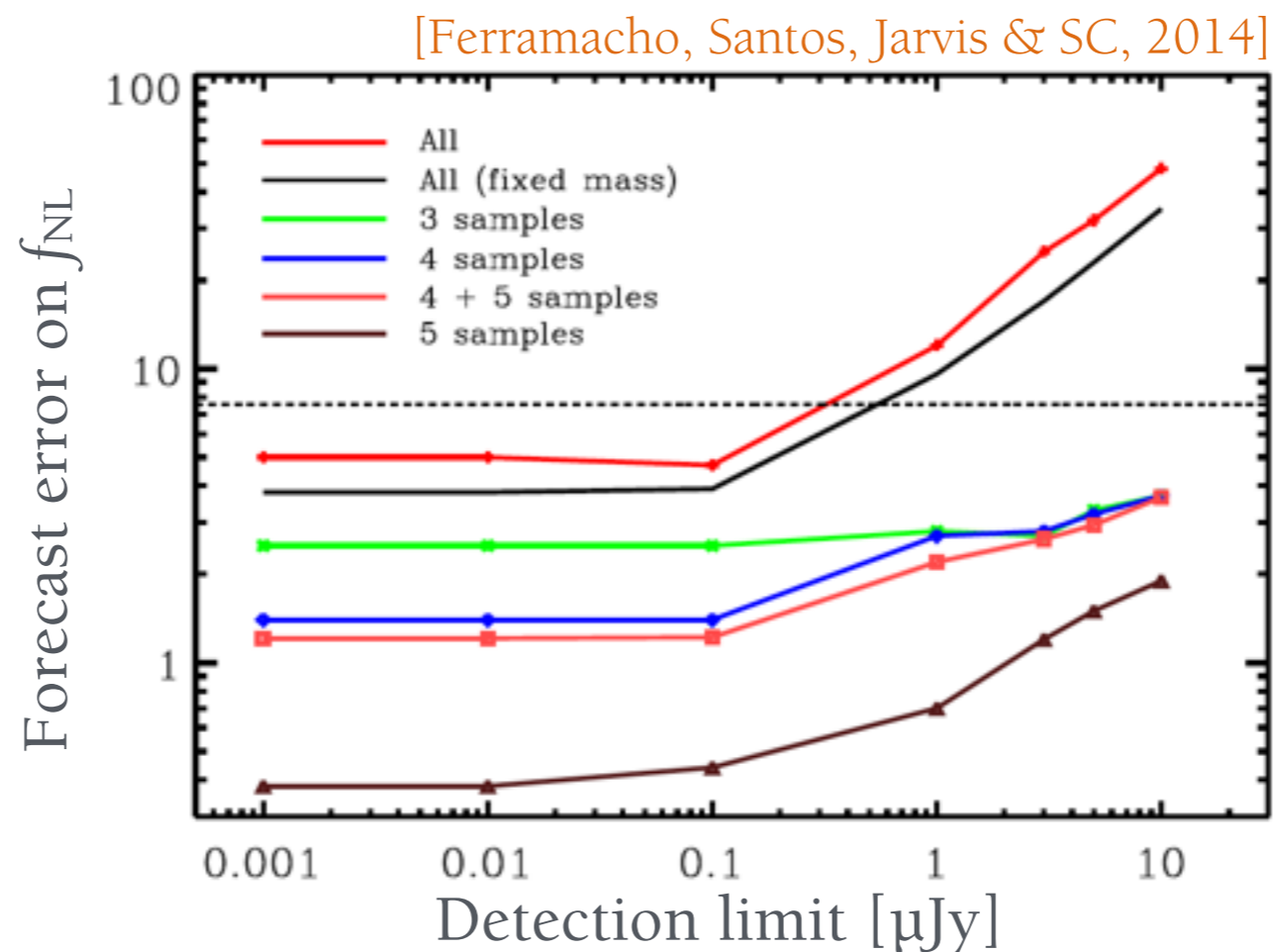Perfect mass knowledge

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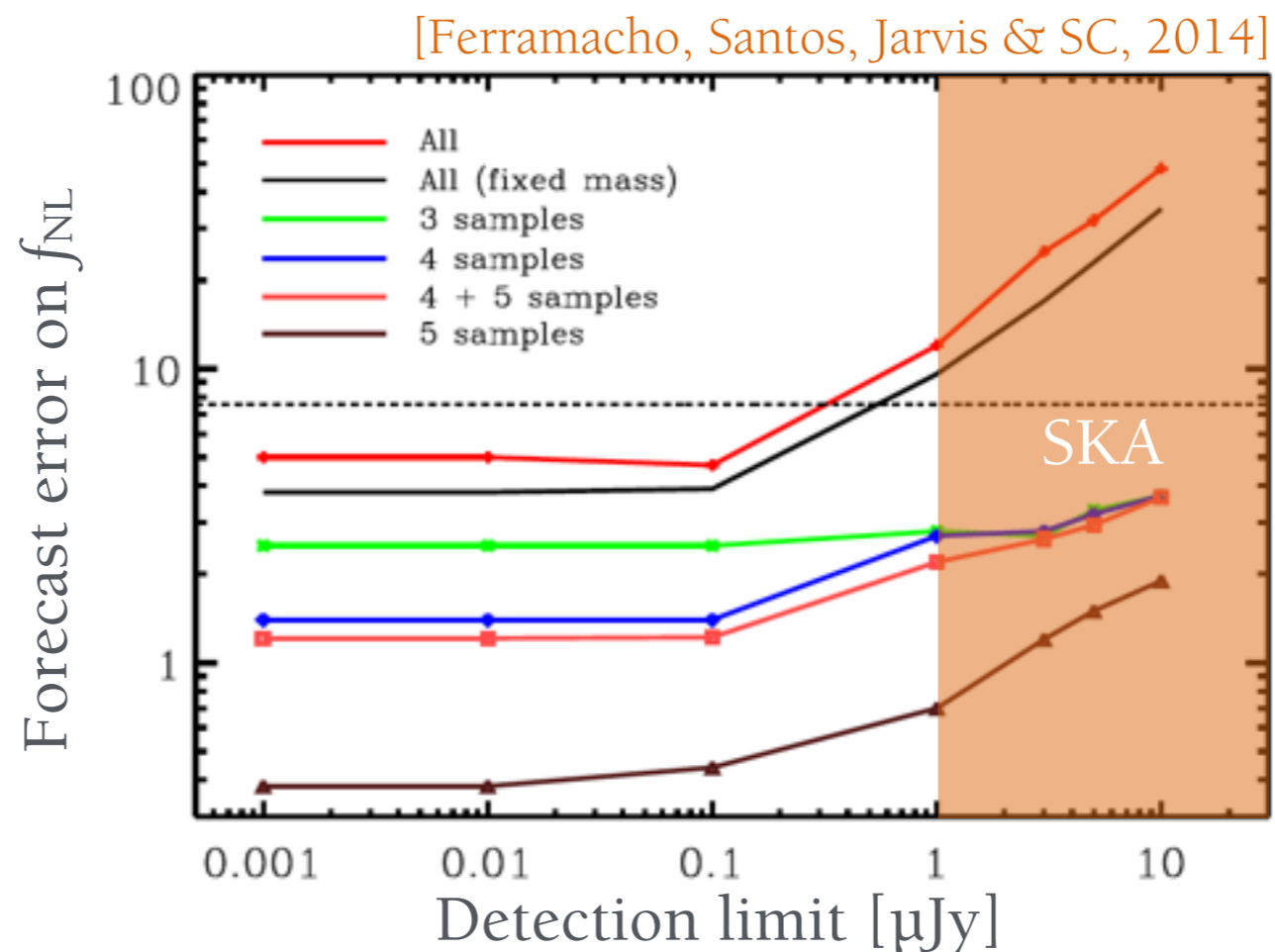[Ferramacho, Santos, Jarvis & SC, 2014]

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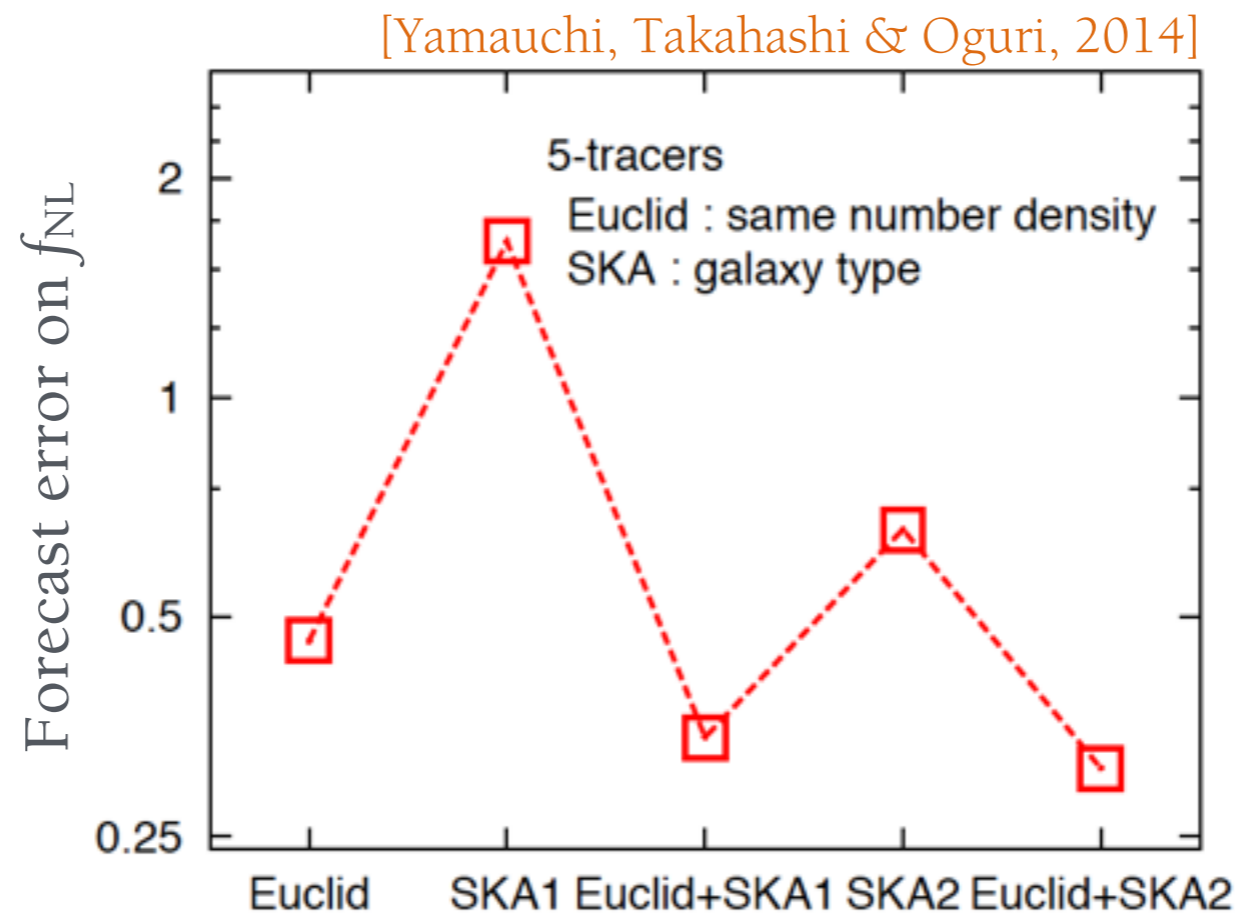[Ferramacho, Santos, Jarvis & SC, 2014]

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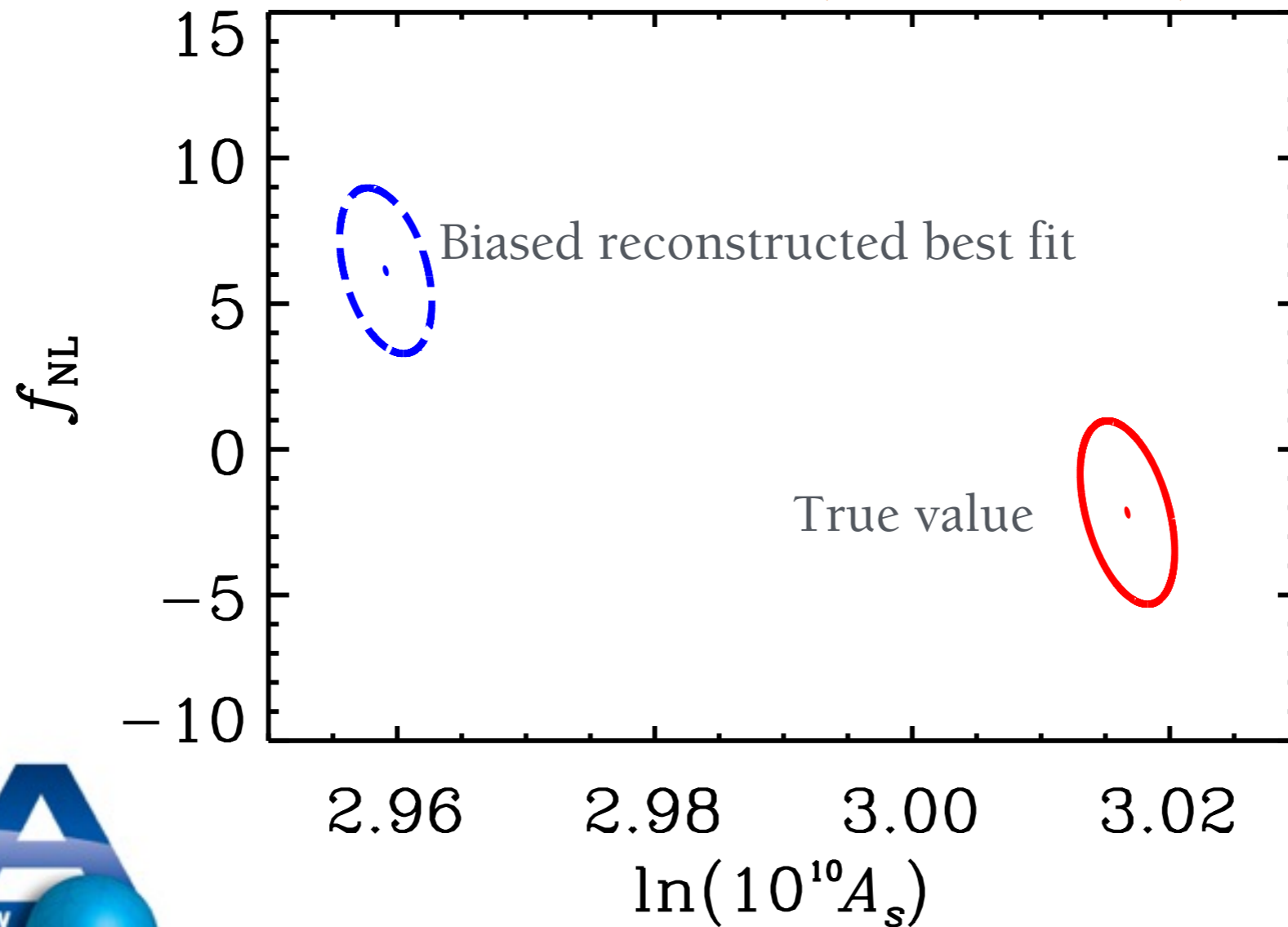
[Yamauchi, Takahashi & Oguri, 2014]

Ultra-Large Scales Matter!

- Neglecting ultra-large scale effects can undermine future cosmological experiments' accuracy

[Heavens, Kitching & Verde, 2007]

Cosmological parameters, p

$b(p)$

δq

Ultra-large scale (extra) parameters, q
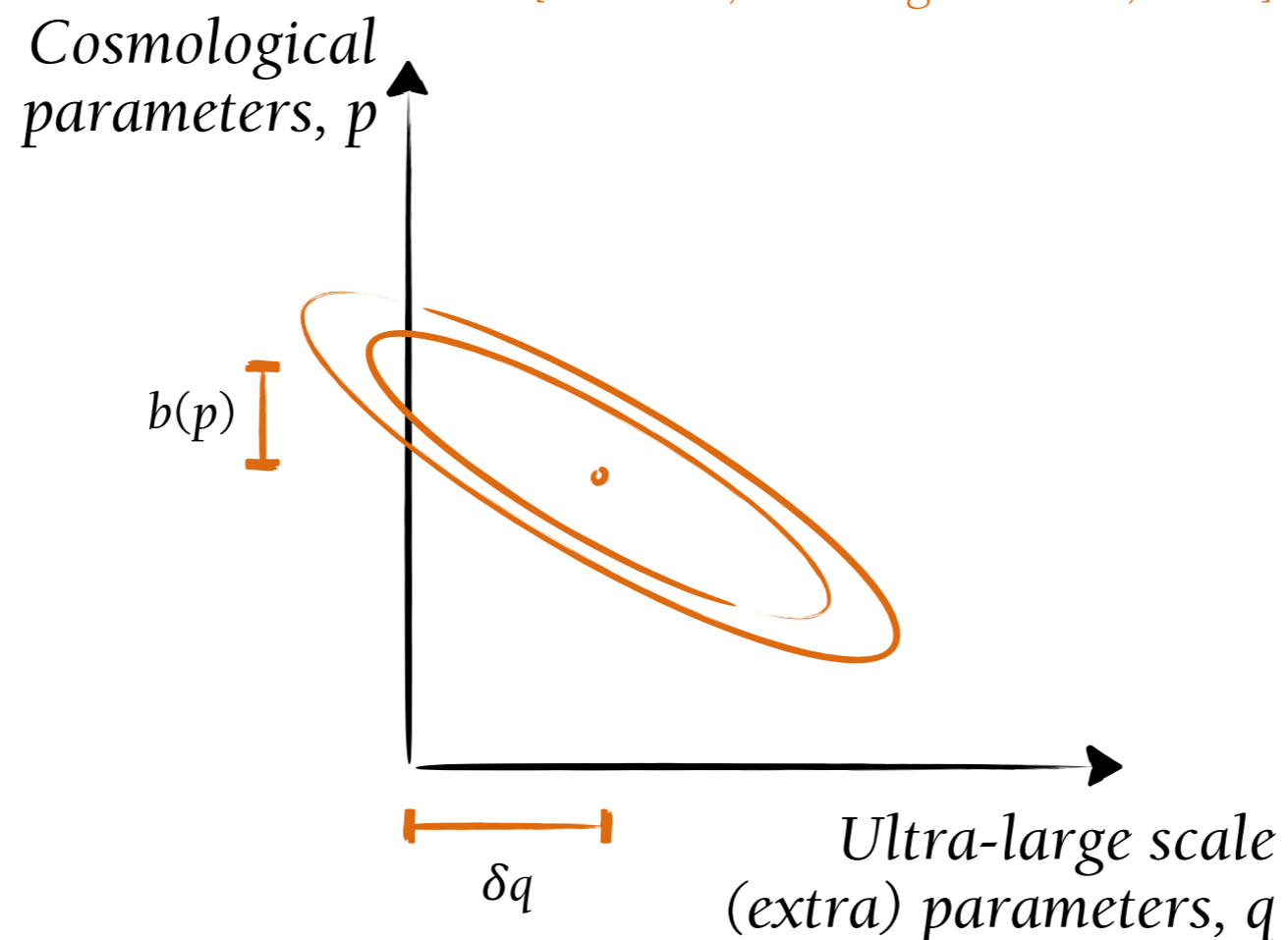
Neglecting Relativistic Effects

[SC, Maartens & Santos, 2015]

Biased reconstructed best fit

True value

$f_{\rm NL}$

$\ln(10^{10}A_s)$

Summary

- The largest scales are a playground for possibly unknown physics
  (modified gravity?)

- They can further confirm Einstein's general relativity
  (tests for relativistic corrections)

- They can improve our knowledge on inflation and the early Universe
  (e.g. primordial non-Gaussianity)

- An incorrect account for ultra-large scale effects may seriously threaten future large-scale cosmological experiments' accuracy